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3rd Generation Partnership Project;
Technical Specification Group Services and System Aspects;
3G Security;
Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS;
Document 1: A5/3 and GEA3 Specifications
(Release 6)

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Foreword

This Technical Specification has been produced by the 3rd Generation Partnership Project (3GPP).

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0 Scope

This specification has been prepared by the 3GPP Task Force, and gives a detailed specification of the **A5/3** encryption algorithms for GSM and ECSD, and of the **GEA3** encryption algorithm for GPRS.

This document is the first of three, which between them form the entire specification of the **A5/3** and **GEA3** algorithms:

- **Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 1: A5/3 and GEA3 Specifications.**
- Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 2: Implementors' Test Data.
- Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 3: Design Conformance Test Data.

The normative part of the specification of the **A5/3** and **GEA3** algorithms is in the main body of this document. The annexes to this document are purely informative. Annex A gives a specification of the 3GPP ***f8*** confidentiality algorithm, bringing out the (deliberate) commonality between it and the **A5/3** and **GEA3** algorithms. Annex B contains illustrations of functional elements of the algorithms, while Annex C contains an implementation program listing of the cryptographic algorithms specified in the main body of this document, written in the programming language C.

Documents 2 and 3 above are also purely informative.

The normative part of the specification of the block cipher (**KASUMI**) on which the **A5/3** and **GEA3** algorithms are based can be found in TS 35.202 [5].

NORMATIVE SECTION

This part of the document contains the normative specifications of the **A5/3** and **GEA3** encryption algorithms.

1 Outline of the normative part

Section 2 introduces the algorithms and describes the notation used in the subsequent sections.

Section 3 specifies a core function **KGCORE**.

Section 4 specifies the encryption algorithm **A5/3** for GSM in terms of the function **KGCORE**.

Section 5 specifies the encryption algorithm **A5/3** for ECSD in terms of the function **KGCORE**.

Section 6 specifies the encryption algorithm **GEA3** for GPRS in terms of the function **KGCORE**.

1.1 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] TS 55.216: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 1: A5/3 and GEA3 Specifications".

[2] TS 55.217: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 2: Implementors' Test Data".

[3] TS 55.218: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the A5/3 Encryption Algorithms for GSM and ECSD, and the GEA3 Encryption Algorithm for GPRS; Document 3: Design Conformance Test Data".

[4] 3GPP TS 35.201: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 1: *f8* and *f9* Specification".

[5] 3GPP TS 35.202: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 2: KASUMI Specification".

2 Introductory information

2.1 Introduction

In this document are specified three ciphering algorithms: **A5/3** for GSM, **A5/3** for ECSD, and **GEA3** for GPRS (including EGPRS). The algorithms are stream ciphers that are used to encrypt/decrypt blocks of data under a confidentiality key $\mathbf{K_C}$. Each of these algorithms is based on the **KASUMI** algorithm that is specified in reference TS 35.202 [5]. **KASUMI** is a block cipher that produces a 64-bit output from a 64-bit input under the control of a 128-bit key. The algorithms defined here use **KASUMI** in a form of output-feedback mode as a keystream generator.

The three algorithms are all very similar. We first define a core keystream generator function **KGCORE** (section 3); we then specify each of the three algorithms in turn (sections 4, 5 and 6) in terms of this core function.

2.1 Notation

2.1.1 Radix

We use the prefix **0x** to indicate **hexadecimal** numbers.

2.1.2 Conventions

We use the assignment operator '=', as used in several programming languages. When we write

<variable> = *<expression>*

we mean that *<variable>* assumes the value that *<expression>* had before the assignment took place. For instance,

$$x = x + y + 3$$

means

(new value of x) becomes (old value of x) + (old value of y) + 3.

2.1.3 Bit/Byte ordering

All data variables in this specification are presented with the most significant bit (or byte) on the left hand side and the least significant bit (or byte) on the right hand side. Where a variable is broken down into a number of sub-strings, the left most (most significant) sub-string is numbered 0, the next most significant is numbered 1 and so on through to the least significant.

For example an n-bit **STRING** is subdivided into 64-bit substrings $\mathbf{SB_0, SB_1 \ldots SB_i}$ so if we have a string:

0x0123456789ABCDEFFEDCBA987654321086545381AB594FC28786404C50A37…

we have:

$\mathbf{SB_0}$ = 0x0123456789ABCDEF
$\mathbf{SB_1}$ = 0xFEDCBA9876543210
$\mathbf{SB_2}$ = 0x86545381AB594FC2
$\mathbf{SB_3}$ = 0x8786404C50A37…

In binary this would be:

000000010010001101000101011001111000100110101011110011011110111111111110…

with $\mathbf{SB_0}$ = 0000000100100011010001010110011110001001101010111100110111101111
$\mathbf{SB_1}$ = 1111111011011100101110101001100001110110010101000011001000010000
$\mathbf{SB_2}$ = 1000011001010100010100111000000110101011010110010100111111000010
$\mathbf{SB_3}$ = 1000011110000110010000000100110001010000101000110111…

2.1.4 List of Symbols

=	The assignment operator.
$\oplus$	The bitwise exclusive-OR operation
$\|\|$	The concatenation of the two operands.
$\mathrm{KASUMI}[x]_k$	The output of the **KASUMI** algorithm applied to input value **x** using the key **k**.
X[i]	The ith bit of the variable **X**. (**X = X[0] || X[1] || X[2] || …..**).
Y{i}	The ith octet of the variable **Y**. (**Y = Y{0} || Y{1} || Y{2} || …..**).
Z_i	The ith 64-bit block of the variable **Z**. ($\mathbf{Z = Z_0 \| Z_1 \| Z_2 \| \ldots}$).

2.3 List of Variables

A	a 64-bit register that is used within the **KGCORE** function to hold an intermediate value.
BLKCNT	a 64-bit counter used in the **KGCORE** function.
BLOCK1	a string of keystream bits output by the **A5/3** algorithm — 114 bits for GSM, 348 bits for ECSD.
BLOCK2	a string of keystream bits output by the **A5/3** algorithm — 114 bits for GSM, 348 bits for ECSD.
BLOCKS	an integer variable indicating the number of successive applications of **KASUMI** that need to be performed.
CA	an 8-bit input to the **KGCORE** function.
CB	a 5-bit input to the **KGCORE** function.
CC	a 32-bit input to the **KGCORE** function.
CD	a 1-bit input to the **KGCORE** function.

CE a 16-bit input to the **KGCORE** function.

CK a 128-bit input to the **KGCORE** function.

CL an integer input to the **KGCORE** function, in the range $1 \ldots 2^{19}$ inclusive, specifying the number of output bits for **KGCORE** to produce.

CO the output bitstream (**CL** bits) from the **KGCORE** function.

COUNT a 22-bit frame dependent input to both the GSM and ECSD **A5/3** algorithms.

DIRECTION a 1-bit input to the **GEA3** algorithm, indicating the direction of transmission (uplink or downlink).

INPUT a 32-bit frame dependent input to the **GEA3** algorithm.

K_C the cipher key that is an input to each of the three cipher algorithms defined here. Although at the time of writing the standards specify that K_C is 64 bits long, the algorithm specifications here allow it to be of any length between 64 and 128 inclusive, to allow for possible future enhancements to the standards.

KLEN the length of K_C in bits, between 64 and 128 inclusive (see above).

KM a 128-bit constant that is used to modify a key. This is used in the **KGCORE** function.

KS[i] the ith bit of keystream produced by the keystream generator in the **KGCORE** function.

KSB_i the ith block of keystream produced by the keystream generator in the **KGCORE** function. Each block of keystream comprises 64 bits.

M an input to the **GEA3** algorithm, specifying the number of octets of output to produce.

OUTPUT the stream of output octets from the **GEA3** algorithm.

3 Core function KGCORE

3.1 Introduction

In this section we define a general-purpose keystream generation function **KGCORE**. The individual encryption algorithms for GSM, GPRS and ECSD will each be defined in subsequent sections by mapping the relevant inputs to the inputs of **KGCORE**, and mapping the output of **KGCORE** to the relevant output.

3.2 Inputs and Outputs

The inputs to **KGCORE** are given in table 1, the output in table 2:

Table 1: KGCORE inputs

Parameter	Comment
CA	8 bits CA[0]…CA[7]
CB	5 bits CB[0]…CB[4]
CC	32 bits CC[0]…CC[31]
CD	A single bit CD[0]
CE	16 bits CE[0]…CE[15] (see Note 1 below)
CK	128 bits CK[0]….CK[127]
CL	An integer in the range $1 \ldots 2^{19}$ inclusive, specifying the number of output bits to produce

Table 2: KGCORE output

Parameter	Comment
CO	CL bits CO[0]…CO[CL-1]

NOTE 1: All the algorithms specified in this document assign a constant, all-zeroes value to **CE**. More general use of **CE** is, however, available for possible future uses of **KGCORE**.

3.3 Components and Architecture

(See figure B.1, Annex B).

The function **KGCORE** is based on the block cipher **KASUMI** that is specified in TS 35.202 [5]. **KASUMI** is used in a form of output-feedback mode and generates the output bitstream in multiples of 64 bits.

The feedback data is modified by static data held in a 64-bit register **A**, and an (incrementing) 64-bit counter **BLKCNT**.

3.4 Initialisation

In this section we define how the keystream generator is initialised with the input variables before the generation of keystream bits as output.

We set the 64-bit register **A** to **CC || CB || CD || 0 0 || CA || CE**

i.e. **A = CC[0]…CC[31] CB[0]…CB[4] CD[0] 0 0 CA[0]…CA[7] CE[0]…CE[15]**

We set the key modifier **KM** to 0x55555555555555555555555555555555

We set $\mathbf{KSB_0}$ to zero.

One operation of **KASUMI** is then applied to the register **A**, using a modified version of the confidentiality key.

$$\mathbf{A = KASUMI[\ A\ ]_{CK \oplus KM}}$$

3.5 Keystream Generation

Once the keystream generator has been initialised in the manner defined in section 3.4, it is ready to be used to generate keystream bits. The keystream generator produces bits in blocks of 64 at a time, but the number **CL** of output bits to produce may not be a multiple of 64; between 0 and 63 of the least significant bits are therefore discarded from the last block, depending on the total number of bits specified by **CL**.

So let **BLOCKS** be equal to (**CL**/64) rounded up to the nearest integer. (For instance, if **CL** = 128 then **BLOCKS** = 2; if **CL** = 129 then **BLOCKS** = 3.)

To generate each keystream block (**KSB**) we perform the following operation:

For each integer **n** with 1 ≤ **n** ≤ **BLOCKS** we define:

$$\mathbf{KSB_n = KASUMI[\ A \oplus BLKCNT \oplus KSB_{n-1}]_{CK}}$$

where **BLKCNT = n-1**

The individual bits of the output are extracted from $\mathbf{KSB_1}$ to $\mathbf{KSB_{BLOCKS}}$ in turn, most significant bit first, by applying the operation:

For **n** = 1 to **BLOCKS**, and for each integer ***i*** with 0 ≤ ***i*** ≤ 63 we define:

$$\mathbf{CO[((n-1)*64)+i] = KSB_n[i]}$$

4 A5/3 algorithm for GSM encryption

4.1 Introduction

The GSM **A5/3** algorithm produces two 114-bit keystream strings, one of which is used for uplink encryption/decryption and the other for downlink encryption/decryption.

We define this algorithm in terms of the core function **KGCORE**.

4.2 Inputs and Outputs

The inputs to the algorithm are given in table 3, the output in table 4:

Table 3: GSM A5/3 inputs

Parameter	Size (bits)	Comment
COUNT	22	Frame dependent input **COUNT[0]…COUNT[21]**
K_C	KLEN	Cipher key **K_C[0]… K_C[KLEN-1]**, where **KLEN** is in the range 64…128 inclusive (see Notes 1 and 2 below)

Table 4: GSM A5/3 outputs

Parameter	Size (bits)	Comment
BLOCK1	114	Keystream bits **BLOCK1[0]…BLOCK1[113]**
BLOCK2	114	Keystream bits **BLOCK2[0]…BLOCK2[113]**

NOTE 1: The specification of the **A5/3** algorithm only allows KLEN to be of value 64.
NOTE 2: It must be assumed that K_C is unstructured data — it must not be assumed, for instance, that any bits of K_C have predetermined values.

4.3 Function Definition

(See figure B.2, Annex B).

We define the function by mapping the GSM **A5/3** inputs onto the inputs of the core function **KGCORE**, and mapping the output of **KGCORE** onto the outputs of GSM **A5/3**.

So we define:

CA[0]…CA[7] = 0 0 0 0 1 1 1 1

CB[0]…CB[4] = 0 0 0 0 0

CC[0]…CC[9] = 0 0 0 0 0 0 0 0 0 0

CC[10]…CC[31] = COUNT[0]…COUNT[21]

CD[0] = 0

CE[0]…CE[15] = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

CK[0]…CK[KLEN-1] = K_C[0]…K_C[KLEN-1]

If **KLEN** < 128 then

CK[KLEN]…CK[127] = K_C[0]…K_C[127 – KLEN]

(So in particular if **KLEN** = 64 then **CK** = **K_C || K_C**)

CL = 228

Apply **KGCORE** to these inputs to derive the output **CO[0]…CO[227]**.

Then define:

BLOCK1[0]…BLOCK1[113] = **CO[0]…CO[113]**

BLOCK2[0]…BLOCK2[113] = **CO[114]…CO[227]**

5 A5/3 algorithm for ECSD encryption

5.1 Introduction

The ECSD **A5/3** algorithm produces two 348-bit keystream strings, one of which is used for uplink encryption/decryption and the other for downlink encryption/decryption.

We define this algorithm in terms of the core function **KGCORE**.

5.2 Inputs and Outputs

The inputs to the algorithm are given in table 5, the output in table 6:

Table 5: ECSD A5/3 inputs

Parameter	Size (bits)	Comment
COUNT	22	Frame dependent input **COUNT[0]…COUNT[21]**
$\mathbf{K_C}$	KLEN	Cipher key $\mathbf{K_C}$**[0]…** $\mathbf{K_C}$**[KLEN-1]**, where **KLEN** is in the range 64…128 inclusive (see Notes 1 and 2 below)

Table 6: ECSD A5/3 outputs

Parameter	Size (bits)	Comment
BLOCK1	348	Keystream bits **BLOCK1[0]…BLOCK1[347]**
BLOCK2	348	Keystream bits **BLOCK2[0]…BLOCK2[347]**

NOTE 1: The specification of the **A5/3** algorithm only allows KLEN to be of value 64.

NOTE 2: It must be assumed that $\mathbf{K_C}$ is unstructured data — it must not be assumed, for instance, that any bits of $\mathbf{K_C}$ have predetermined values.

5.3 Function Definition

(See figure B.3, Annex B).

We define the function by mapping the ECSD **A5/3** inputs onto the inputs of the core function **KGCORE**, and mapping the output of **KGCORE** onto the outputs of ECSD **A5/3**.

So we define:

CA[0]…CA[7] = 1 1 1 1 0 0 0 0

CB[0]…CB[4] = 0 0 0 0 0

CC[0]…CC[9] = 0 0 0 0 0 0 0 0 0 0

CC[10]…CC[31] = COUNT[0]…COUNT[21]

CD[0] = 0

CE[0]…CE[15] = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

CK[0]…CK[KLEN-1] = K_C[0]…K_C[KLEN-1]

If **KLEN** < 128 then

CK[KLEN]…CK[127] = K_C[0]…K_C[127 – KLEN]

(So in particular if **KLEN** = 64 then **CK = K_C || K_C**)

CL = 696

Apply **KGCORE** to these inputs to derive the output **CO[0]…CO[695]**.

Then define:

BLOCK1[0]…BLOCK1[347] = **CO[0]…CO[347]**

BLOCK2[0]…BLOCK2[347] = **CO[348]…CO[695]**

6 GEA3 algorithm for GPRS encryption

6.1 Introduction

The GPRS **GEA3** algorithm produces an M-byte keystream string. M can vary; in this specification we assume that M will never exceed 2^{16} = 65536.

We define this algorithm in terms of the core function **KGCORE**.

6.2 Inputs and Outputs

The inputs to the algorithm are given in table 7, the output in table 8:

Table 7: GEA3 inputs

Parameter	Size (bits)	Comment
INPUT	32	Frame dependent input **INPUT[0]…INPUT[31]**
DIRECTION	1	Direction of transmission indicator **DIRECTION[0]**
K_C	KLEN	Cipher key **K_C[0]… K_C[KLEN-1]**, where **KLEN** is in the range 64…128 inclusive (see Notes 1 and 2 below)
M		Number of octets of output required, in the range 1 to 65536 inclusive

Table 8: GEA3 outputs

Parameter	Size (bits)	Comment
OUTPUT	8**M**	Keystream octets **OUTPUT{0}…OUTPUT{M-1}**

NOTE 1: The specification of the **GEA3** algorithm only allows KLEN to be of value 64.
NOTE 2: It must be assumed that **K_C** is unstructured data — it must not be assumed, for instance, that any bits of **K_C** have predetermined values.

6.3 Function Definition

(See figure B.4, Annex B).

We define the function by mapping the **GEA3** inputs onto the inputs of the core function **KGCORE**, and mapping the output of **KGCORE** onto the outputs of **GEA3**.

So we define:

CA[0]…CA[7] = 1 1 1 1 1 1 1 1

CB[0]…CB[4] = 0 0 0 0 0

CC[0]…CC[31] = INPUT[0]…INPUT[31]

CD[0] = DIRECTION[0]

CE[0]…CE[15] = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

CK[0]…CK[KLEN-1] = $\mathbf{K_C}$**[0]…**$\mathbf{K_C}$**[KLEN-1]**

If **KLEN** < 128 then

CK[KLEN]…CK[127] = $\mathbf{K_C}$**[0]…**$\mathbf{K_C}$**[127 – KLEN]**

(So in particular if **KLEN** = 64 then **CK =** $\mathbf{K_C}$ || $\mathbf{K_C}$)

CL = 8**M**

Apply **KGCORE** to these inputs to derive the output **CO[0]…CO[8M-1]**.

Then for $0 \le i \le$ **M-1** define:

OUTPUT{*i*} = **CO[8*i*]…CO[8*i* + 7]**

where **CO[8*i*]** is the most significant bit of the octet.

INFORMATIVE SECTION

This part of the document is purely informative and does not form part of the normative specification of A5/3 and GEA3.

Annex A (informative): Specification of the 3GPP Confidentiality Algorithm *f*8

A.1 Introduction

The algorithms defined in this specification have been designed to have much in common with the 3GPP confidentiality algorithm, to ease simultaneous implementation of multiple algorithms. To clarify this, a specification of ***f*8** is given here in terms of the core function **KGCORE**. For the definitive specification of ***f*8**, the reader is referred to TS 35.202 [5].

A.2 Inputs and Outputs

The inputs to the algorithm are given in table A.1, the output in table A.2:

Table A.1: f8 inputs

Parameter	Size (bits)	Comment
COUNT	32	Frame dependent input **COUNT[0]…COUNT[31]**
BEARER	5	Bearer identity **BEARER[0]…BEARER[4]**
DIRECTION	1	Direction of transmission **DIRECTION[0]**
CK	128	Confidentiality key **CK[0]…CK[127]**
LENGTH		The number of bits to be encrypted/decrypted (1-20000)

Table A.2: f8 output

Parameter	Size (bits)	Comment
KS	1-20000	Keystream bits **KS[0]…KS[LENGTH-1]**

NOTE: The definitive specification of ***f*8** includes a bitstream **IBS** amongst the inputs, and gives the output as a bitstream **OBS**; both of these bitstreams are **LENGTH** bits long. **OBS** is obtained by the bitwise exclusive-or of **IBS** and **KS**. We present just the keystream generator part of ***f*8** here, for closer comparison with **A5/3** and **GEA3**.

A.3 Function Definition

(See figure 5, Annex B).

We define the function by mapping the ***f*8** inputs onto the inputs of the core function **KGCORE**, and mapping the output of **KGCORE** onto the outputs of ***f*8**.

So we define:

CA[0]…CA[7] = 0 0 0 0 0 0 0 0

CB[0]…CB[4] = BEARER[0]…BEARER[4]

CC[0]…CC[31] = COUNT[0]…COUNT[31]

CD[0] = DIRECTION[0]

CE[0]…CE[15] = 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

CK[0]…CK[127] = CK[0]…CK[127]

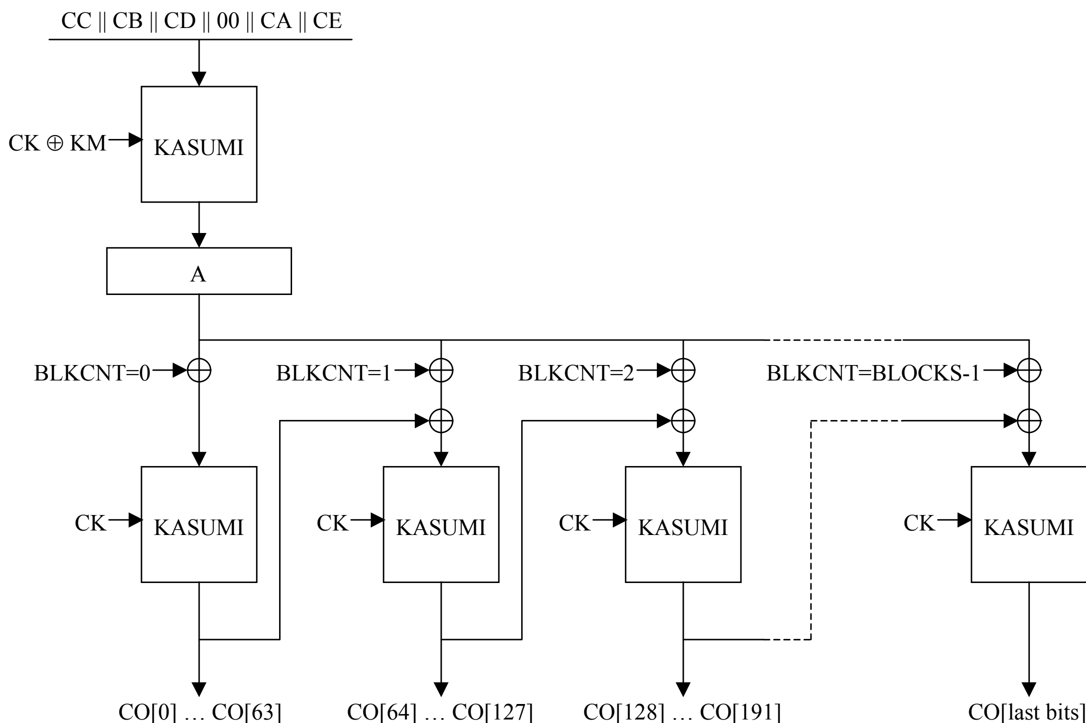
CL = LENGTH

Apply **KGCORE** to these inputs to derive the output **CO[0]…CO[LENGTH-1]**.

Then define:

KS[0]…KS[LENGTH-1] = **CO[0]…CO[LENGTH-1]**

Annex B (informative): Figures of the Algorithms



NOTE: **BLKCNT** is specified as a 64-bit counter so there is no ambiguity in the expression **A** ⊕ **BLKCNT** ⊕ $\mathbf{KSB_{n-1}}$ where all operands are of the same size. In a practical implementation, where the keystream generator is required to produce no more than a certain number of bits, only the least significant few bits of the counter need to be realised.

Figure B.1: KGCORE Core Keystream Generator Function

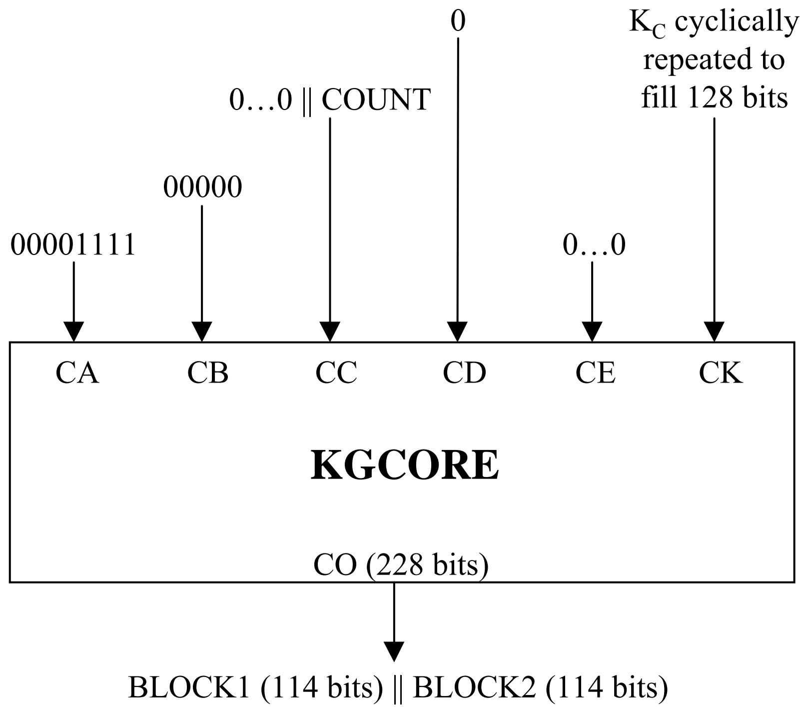


Figure B.2: GSM A5/3 Keystream Generator Function

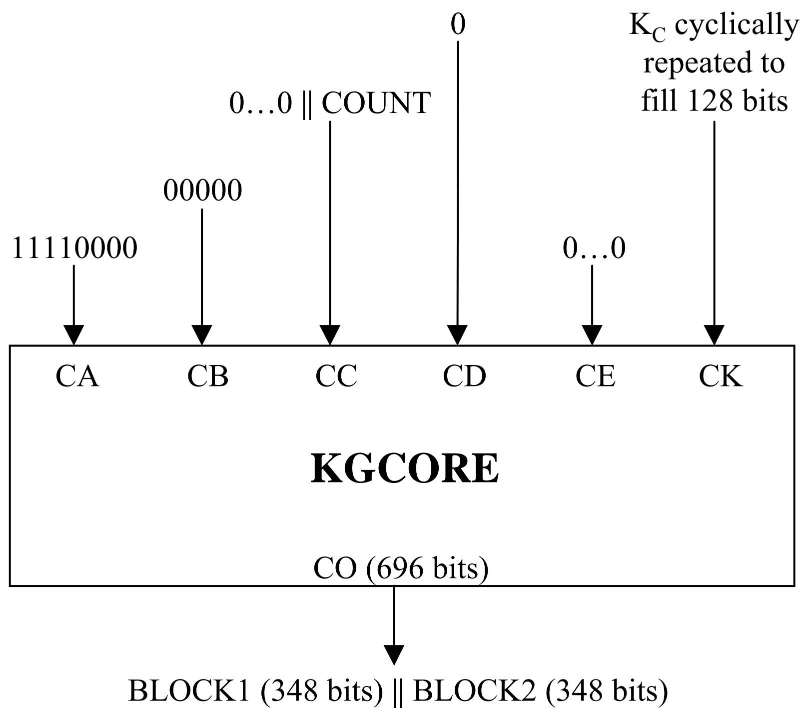


Figure B.3: ECSD A5/3 Keystream Generator Function

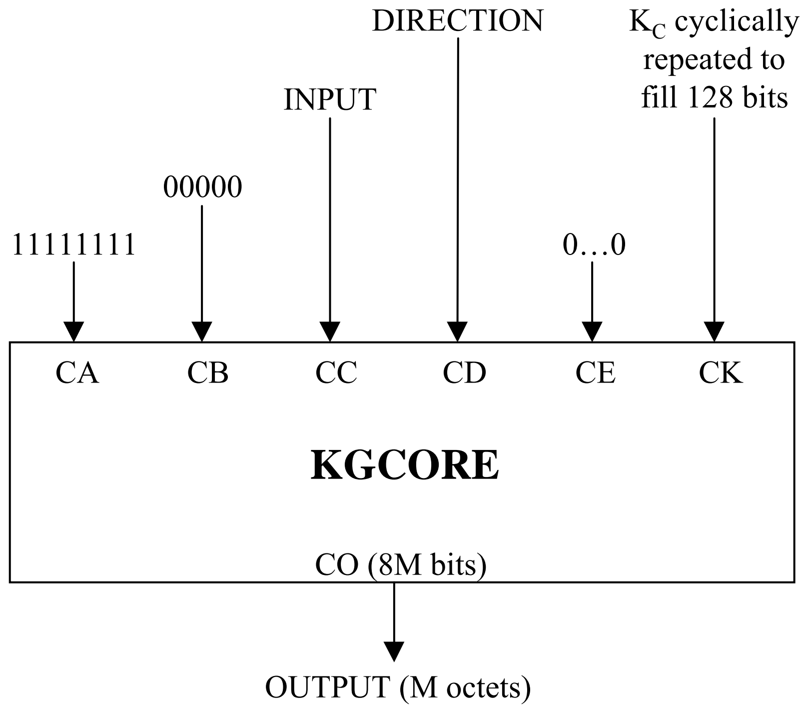


Figure B.4: GEA3 Keystream Generator Function

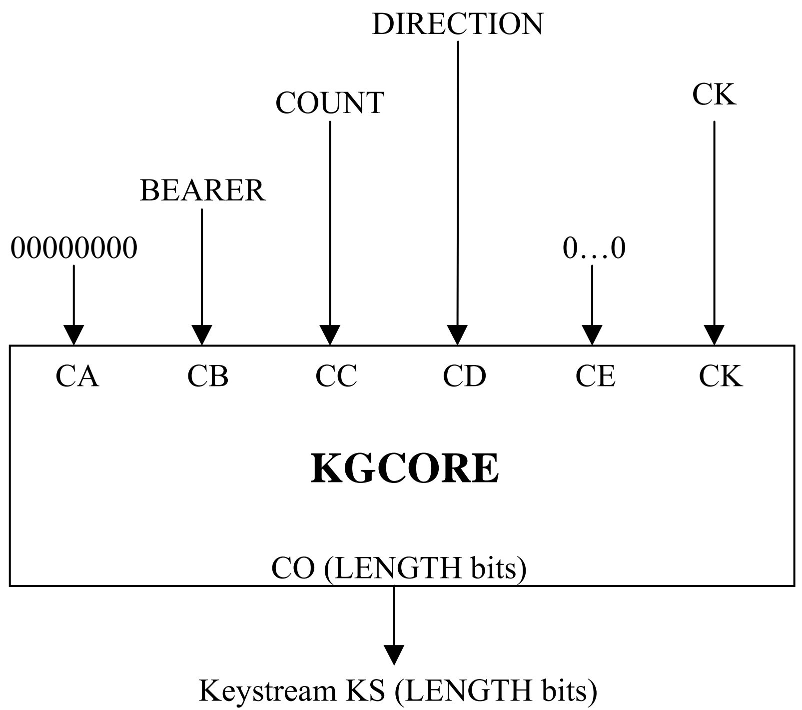


Figure B.5: 3GPP f8 Keystream Generator Function

Table B.1: GSM A5/3, ECSD A5/3, GEA3 and f8 in terms of KGCORE

	GSM A5/3	ECSD A5/3	GEA3	f8
CA	0 0 0 0 1 1 1 1	1 1 1 1 0 0 0 0	1 1 1 1 1 1 1 1	0 0 0 0 0 0 0 0
CB	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	BEARER
CC	0...0||COUNT	0...0||COUNT	INPUT	COUNT
CD	0	0	DIRECTION	DIRECTION
CE	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0			
CK	**KC** repeated to fill 128 bits			CK
CO	BLOCK1||BLOCK2	BLOCK1||BLOCK2	OUTPUT	KS

Annex C (informative): Simulation Program Listings

kasumi.h

```
/*---------------------------------------------------------
 *                  Kasumi.h
 *---------------------------------------------------------*/

typedef unsigned  char   u8;
typedef unsigned short  u16;
typedef unsigned   int  u32;

/*----- a 64-bit structure to help with endian issues -----*/

typedef union {
    u32 b32[2];
    u16 b16[4];
    u8  b8[8];
} REGISTER64;

/*------------- prototypes --------------------------------*/

void KeySchedule( u8 *key );
void Kasumi( u8 *data );
```

kasumi.c

```
/*-----------------------------------------------------------------------
 *                      Kasumi.c
 *-----------------------------------------------------------------------
 *
 *  A sample implementation of KASUMI, the core algorithm for the
 *  3GPP Confidentiality and Integrity algorithms.
 *
 *  This has been coded for clarity, not necessarily for efficiency.
 *
 *  This will compile and run correctly on both Intel (little endian)
 *  and Sparc (big endian) machines. (Compilers used supported 32-bit ints).
 *
 *  Version 1.1     08 May 2000
 *
 *-----------------------------------------------------------------------*/

#include "Kasumi.h"

/*--------- 16 bit rotate left ------------------------------------------*/

#define ROL16(a,b) (u16)((a<<b)|(a>>(16-b)))

/*------- unions: used to remove "endian" issues ------------------------*/

typedef union {
    u32 b32;
    u16 b16[2];
    u8  b8[4];
} DWORD;

typedef union {
    u16 b16;
    u8  b8[2];
} WORD;

/*-------- globals: The subkey arrays -----------------------------------*/

static u16 KLi1[8], KLi2[8];
static u16 KOi1[8], KOi2[8], KOi3[8];
static u16 KIi1[8], KIi2[8], KIi3[8];

 /*---------------------------------------------------------------------
 *  FI()
 *      The FI function (fig 3).  It includes the S7 and S9 tables.
```

```
 *      Transforms a 16-bit value.
 *-----------------------------------------------------------------------*/
static u16 FI( u16 in, u16 subkey )
{
    u16 nine, seven;
    static u16 S7[] = {
        54, 50, 62, 56, 22, 34, 94, 96, 38, 6, 63, 93, 2, 18,123, 33,
        55,113, 39,114, 21, 67, 65, 12, 47, 73, 46, 27, 25,111,124, 81,
        53, 9,121, 79, 52, 60, 58, 48,101,127, 40,120,104, 70, 71, 43,
        20,122, 72, 61, 23,109, 13,100, 77, 1, 16, 7, 82, 10,105, 98,
        117,116, 76, 11, 89,106, 0,125,118, 99, 86, 69, 30, 57,126, 87,
        112, 51, 17, 5, 95, 14, 90, 84, 91, 8, 35,103, 32, 97, 28, 66,
        102, 31, 26, 45, 75, 4, 85, 92, 37, 74, 80, 49, 68, 29,115, 44,
        64,107,108, 24,110, 83, 36, 78, 42, 19, 15, 41, 88,119, 59, 3};
    static u16 S9[] = {
        167,239,161,379,391,334,  9,338, 38,226, 48,358,452,385, 90,397,
        183,253,147,331,415,340, 51,362,306,500,262, 82,216,159,356,177,
        175,241,489, 37,206, 17,  0,333, 44,254,378, 58,143,220, 81,400,
         95,  3,315,245, 54,235,218,405,472,264,172,494,371,290,399, 76,
        165,197,395,121,257,480,423,212,240, 28,462,176,406,507,288,223,
        501,407,249,265, 89,186,221,428,164, 74,440,196,458,421,350,163,
        232,158,134,354, 13,250,491,142,191, 69,193,425,152,227,366,135,
        344,300,276,242,437,320,113,278, 11,243, 87,317, 36, 93,496, 27,
        487,446,482, 41, 68,156,457,131,326,403,339, 20, 39,115,442,124,
        475,384,508, 53,112,170,479,151,126,169, 73,268,279,321,168,364,
        363,292, 46,499,393,327,324, 24,456,267,157,460,488,426,309,229,
        439,506,208,271,349,401,434,236, 16,209,359, 52, 56,120,199,277,
        465,416,252,287,246,  6, 83,305,420,345,153,502, 65, 61,244,282,
        173,222,418, 67,386,368,261,101,476,291,195,430, 49, 79,166,330,
        280,383,373,128,382,408,155,495,367,388,274,107,459,417, 62,454,
        132,225,203,316,234, 14,301, 91,503,286,424,211,347,307,140,374,
         35,103,125,427, 19,214,453,146,498,314,444,230,256,329,198,285,
         50,116, 78,410, 10,205,510,171,231, 45,139,467, 29, 86,505, 32,
         72, 26,342,150,313,490,431,238,411,325,149,473, 40,119,174,355,
        185,233,389, 71,448,273,372, 55,110,178,322, 12,469,392,369,190,
          1,109,375,137,181, 88, 75,308,260,484, 98,272,370,275,412,111,
        336,318,  4,504,492,259,304, 77,337,435, 21,357,303,332,483, 18,
         47, 85, 25,497,474,289,100,269,296,478,270,106, 31,104,433, 84,
        414,486,394, 96, 99,154,511,148,413,361,409,255,162,215,302,201,
        266,351,343,144,441,365,108,298,251, 34,182,509,138,210,335,133,
        311,352,328,141,396,346,123,319,450,281,429,228,443,481, 92,404,
        485,422,248,297, 23,213,130,466, 22,217,283, 70,294,360,419,127,
        312,377,  7,468,194,  2,117,295,463,258,224,447,247,187, 80,398,
        284,353,105,390,299,471,470,184, 57,200,348, 63,204,188, 33,451,
         97, 30,310,219, 94,160,129,493, 64,179,263,102,189,207,114,402,
        438,477,387,122,192, 42,381,  5,145,118,180,449,293,323,136,380,
         43, 66, 60,455,341,445,202,432, 8,237, 15,376,436,464, 59,461};

    /* The sixteen bit input is split into two unequal halves,  *
     * nine bits and seven bits - as is the subkey             */

    nine  = (u16)(in>>7);
    seven = (u16)(in&0x7F);

    /* Now run the various operations */

    nine  = (u16)(S9[nine]  ^ seven);
    seven = (u16)(S7[seven] ^ (nine & 0x7F));

    seven ^= (subkey>>9);
    nine  ^= (subkey&0x1FF);

    nine  = (u16)(S9[nine]  ^ seven);
    seven = (u16)(S7[seven] ^ (nine & 0x7F));

    in = (u16)((seven<<9) + nine);

    return( in );
}

 /*----------------------------------------------------------------------
 * FO()
 *      The FO() function.
 *      Transforms a 32-bit value.  Uses <index> to identify the
 *      appropriate subkeys to use.
 *-----------------------------------------------------------------------*/
static u32 FO( u32 in, int index )
{
```

```
    u16 left, right;

    /* Split the input into two 16-bit words */

    left  = (u16)(in>>16);
    right = (u16) in;

    /* Now apply the same basic transformation three times         */

    left ^= KOi1[index];
    left  = FI( left, KIi1[index] );
    left ^= right;

    right ^= KOi2[index];
    right  = FI( right, KIi2[index] );
    right ^= left;

    left ^= KOi3[index];
    left  = FI( left, KIi3[index] );
    left ^= right;

    in = (((u32)right)<<16)+left;

    return( in );
}

/*---------------------------------------------------------------------
 * FL()
 *      The FL() function.
 *      Transforms a 32-bit value.  Uses <index> to identify the
 *      appropriate subkeys to use.
 *---------------------------------------------------------------------*/
static u32 FL( u32 in, int index )
{
    u16 l, r, a, b;

    /* split out the left and right halves */

    l = (u16)(in>>16);
    r = (u16)(in);

    /* do the FL() operations           */

    a  = (u16) (l & KLi1[index]);
    r ^= ROL16(a,1);

    b  = (u16)(r | KLi2[index]);
    l ^= ROL16(b,1);

    /* put the two halves back together */

    in = (((u32)l)<<16) + r;

    return( in );
}

 /*---------------------------------------------------------------------
 * Kasumi()
 *      the Main algorithm (fig 1).  Apply the same pair of operations
 *      four times.  Transforms the 64-bit input.
 *---------------------------------------------------------------------*/
void Kasumi( u8 *data )
{
    u32 left, right, temp;
    DWORD *d;
    int n;

    /* Start by getting the data into two 32-bit words (endian corect) */

    d = (DWORD*)data;
    left  = (((u32)d[0].b8[0])<<24)+(((u32)d[0].b8[1])<<16)
+(d[0].b8[2]<<8)+(d[0].b8[3]);
    right = (((u32)d[1].b8[0])<<24)+(((u32)d[1].b8[1])<<16)
+(d[1].b8[2]<<8)+(d[1].b8[3]);
    n = 0;
    do{     temp = FL( left, n   );
        temp = FO( temp,  n++ );
        right ^= temp;
```

```
        temp = FO( right, n   );
        temp = FL( temp,   n++ );
        left ^= temp;
    }while( n<=7 );

    /* return the correct endian result */
    d[0].b8[0] = (u8)(left>>24);        d[1].b8[0] = (u8)(right>>24);
    d[0].b8[1] = (u8)(left>>16);        d[1].b8[1] = (u8)(right>>16);
    d[0].b8[2] = (u8)(left>>8);     d[1].b8[2] = (u8)(right>>8);
    d[0].b8[3] = (u8)(left);            d[1].b8[3] = (u8)(right);
}

/*---------------------------------------------------------------------
 * KeySchedule()
 *      Build the key schedule.  Most "key" operations use 16-bit
 *      subkeys so we build u16-sized arrays that are "endian" correct.
 *---------------------------------------------------------------------*/
void KeySchedule( u8 *k )
{
    static u16 C[] = {
        0x0123,0x4567,0x89AB,0xCDEF, 0xFEDC,0xBA98,0x7654,0x3210 };
    u16 key[8], Kprime[8];
    WORD *k16;
    int n;

    /* Start by ensuring the subkeys are endian correct on a 16-bit basis */

    k16 = (WORD *)k;
    for( n=0; n<8; ++n )
        key[n] = (u16)((k16[n].b8[0]<<8) + (k16[n].b8[1]));

    /* Now build the K'[] keys */

    for( n=0; n<8; ++n )
        Kprime[n] = (u16)(key[n] ^ C[n]);

    /* Finally construct the various sub keys */

    for( n=0; n<8; ++n )
    {
        KLi1[n] = ROL16(key[n],1);
        KLi2[n] = Kprime[(n+2)&0x7];
        KOi1[n] = ROL16(key[(n+1)&0x7],5);
        KOi2[n] = ROL16(key[(n+5)&0x7],8);
        KOi3[n] = ROL16(key[(n+6)&0x7],13);
        KIi1[n] = Kprime[(n+4)&0x7];
        KIi2[n] = Kprime[(n+3)&0x7];
        KIi3[n] = Kprime[(n+7)&0x7];
    }
}
/*---------------------------------------------------------------------
 *              e n d    o f    k a s u m i . c
 *---------------------------------------------------------------------*/
```

kgcore.c

```
/*---------------------------------------------------------
 *              KGCORE
 *---------------------------------------------------------
 *
 *  A sample implementation of KGCORE, the heart of the
 *  A5/3 algorithm set.
 *
 *  This has been coded for clarity, not necessarily for
 *  efficiency.
 *
 *  This will compile and run correctly on both Intel
 *  (little endian) and Sparc (big endian) machines.
 *
 *  Version 0.1     13 March 2002
 *
 *---------------------------------------------------------*/

#include "kasumi.h"
#include <stdio.h>
```

```
/*---------------------------------------------------------
 * KGcore()
 *      Given ca, cb, cc, cd, ck, cl generate c0
 *---------------------------------------------------------*/
void KGcore( u8 ca, u8 cb, u32 cc, u8 cd, u8 *ck, u8 *co, int cl )
{
    REGISTER64 A;       /* the modifier         */
    REGISTER64 temp;    /* The working register */
    int i, n;
    u8  key[16],ModKey[16];     /* Modified key      */
    u16 blkcnt;         /* The block counter */

    /* Copy over the key */

    for( i=0; i<16; ++i )
        key[i] = ck[i];

    /* Start by building our global modifier */

    temp.b32[0]  = temp.b32[1]  = 0;
    A.b32[0]     = A.b32[1]     = 0;

    /* initialise register in an endian correct manner*/

    A.b8[0]  = (u8) (cc>>24);
    A.b8[1]  = (u8) (cc>>16);
    A.b8[2]  = (u8) (cc>>8);
    A.b8[3]  = (u8) (cc);
    A.b8[4]  = (u8) (cb<<3);
    A.b8[4] |= (u8) (cd<<2);
    A.b8[5]  = (u8) ca;

    /* Construct the modified key and then "kasumi" A */

    for( n=0; n<16; ++n )
        ModKey[n] = (u8)(ck[n] ^ 0x55);
    KeySchedule( ModKey );
    Kasumi( A.b8 ); /* First encryption to create modifier */

    /* Final initialisation steps */

    blkcnt = 0;
    KeySchedule( key );

    /* Now run the key stream generator */

    while( cl > 0 )
    {
        /* First we calculate the next 64-bits of keystream */

        /* XOR in A and BLKCNT to last value */

        temp.b32[0] ^= A.b32[0];
        temp.b32[1] ^= A.b32[1];
        temp.b8[7]  ^= blkcnt;

        /* KASUMI it to produce the next block of keystream */

        Kasumi( temp.b8 );

        /* Set <n> to the number of bytes of input data *
         * we have to modify.  (=8 if length <= 64)     */

        if( cl >= 64 )
            n = 8;
        else
            n = (cl+7)/8;

        /* copy out the keystream */

        for( i=0; i<n; ++i )
            *co++ = temp.b8[i];
        cl -= 64;       /* done another 64 bits */
        ++blkcnt;       /* increment BLKCNT */
    }
}

/*-------------------------------------------------------------
```

```
 *         e n d    o f    K G c o r e . c
 *-----------------------------------------------------------*/
```

a53f.c

```
/*---------------------------------------------------------
 *             A5/3
 *---------------------------------------------------------
 *
 *  A sample implementation of A5/3, the functions of the
 *  A5/3 algorithm set.
 *
 *  This has been coded for clarity, not necessarily for
 *  efficiency.
 *
 *  This will compile and run correctly on both Intel
 *  (little endian) and Sparc (big endian) machines.
 *
 *  Version 0.1     13 March 2002
 *
 *---------------------------------------------------------*/

#include "kasumi.h"
#include <stdlib.h>

void KGcore( u8 ca, u8 cb, u32 cc, u8 cd, u8 *ck, u8 *co, int cl );

/*---------------------------------------------------------
 * BuildKey()
 *  The KGcore() function expects a 128-bit key.  This
 *  function builds that key from shorter length keys.
 *---------------------------------------------------------*/
static u8 *BuildKey( u8 *k, int len )
{
    static u8 ck[16];       /* Where the key is built */
    int i, n, sf;
    u8 mask[]={0x1,0x3,0x7,0xF,0x1F,0x3F,0x7F,0xFF};

    i = (len+7)/8;          /* Round to nearest byte  */
    if (i > 16 )
        i = 16;             /* limit to 128 bits      */
    for( n=0; n<i; ++n )    /* copy over the key      */
        ck[n] = k[n];
    sf = len%8;             /* Any odd key length?    */

    /* If the key is less than 128-bits we need to replicate *
     * it as many times as is necessary to fill the key.     */

    if( len < 128 )
    {
        n = 0;
        if( sf )    /* Doesn't align to byte boundaries */
        {
            ck[i-1] &= mask[sf];
            ck[i-1] += ck[0]<<sf;
            while( i<16 )
            {
                ck[i] = (ck[n]>>(8-sf)) + (ck[n+1]<<sf);
                ++n;
                ++i;
            }
        }
        else
            while( i<16 )
                ck[i++] = ck[n++];
    }
    return( ck );
}


/*---------------------------------------------------------
 * The basic A5/3 functions.
 *  These follow a standard layout:
 *  - From the supplied key build the 128-bit required by
 *    KGcore()
 *  - Call the KGcore() function with the appropriate
 *    parameters
```

```
 *  - Take the generated Keystream and repackage it
 *    in the required format.
 */

/*---------------------------------------------------------
 * The standard GSM function
 *---------------------------------------------------------*/
void GSM( u8 *key, int klen, int count, u8 *block1, u8 *block2 )
{
    u8 *ck, data[32];
    int i;

    ck=BuildKey( key, klen );
    KGcore( 0x0F, 0, count, 0, ck, data, 228 );
    for( i=0; i<15; ++i )
    {
        block1[i] = data[i];
        block2[i] = (data[i+14]<<2) + (data[i+15]>>6);
    }
    block1[14] &= 0xC0;
    block2[14] &= 0xC0;
}

/*---------------------------------------------------------
 * The standard GSM ECSD function
 *---------------------------------------------------------*/
void ECSD( u8 *key, int klen, int count, u8 *block1, u8 *block2 )
{
    u8 *ck, data[87];
    int i;

    ck=BuildKey( key, klen );
    KGcore( 0xF0, 0, count, 0, ck, data, 696 );
    for( i=0; i<44; ++i )
    {
        block1[i] = data[i];
        block2[i] = (data[i+43]<<4) + (data[i+44]>>4);
    }
    block1[43] &= 0xF0;
    block2[43] &= 0xF0;
}

/*---------------------------------------------------------
 * The standard GEA3 function
 *---------------------------------------------------------*/
void GEA3( u8 *key, int klen, u32 input, u8 direction, u8 *block, int m )
{
    u8 *ck, *data;
    int i;


    data = malloc( m );
    ck=BuildKey( key, klen );
    KGcore( 0xFF, 0, input, direction, ck, data, m*8 );
    for( i=0; i<m; ++i )
        block[i] = data[i];
    free( data );
}

/*---------------------------------------------------------
 *  E n d  o f  A 5 3 f . c
 *---------------------------------------------------------*/
```

a53f.h

```
void GSM( u8 *key, int klen, int count, u8 *block1, u8 *block2 );
void ECSD( u8 *key, int klen, int count, u8 *block1, u8 *block2 );
void GEA3( u8 *key, int klen, u32 input, u8 direction, u8 *block, int m );
```

Annex D (informative): Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2002-05	-	-	-	-	ETSI SAGE first publication		SAGE V1.0
2002-07	-	-	-	-	Agreed at SA WG3 #24 for presentation to TSG SA #17 for approval. Converted into 3GPP TS format as TS 55.216 (Technically equivalent to SAGE V1.0)	SAGE V1.0	1.0.0
2002-09	SP-17	SP-020506	-	-	Approved for Release 6 - version 6.0.0	1.0.0	6.0.0
2002-12	SP-18	SP-020721	001	-	EGPRS algoritm	6.0.0	6.1.0
2003-09	SP-19	SP-030490	002	-	Clarification on the usage of the Key length	6.1.0	6.2.0